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जल उपचार संयंत्र में रासायनिक कौयगुलांट और कीटाणुनाशक का चयन — दिशा-निर्देश

Selection of Chemical Coagulant and Disinfectant in a Water Treatment Plant — Guidelines

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भारतीय मानक ब्यूरो
BUREAU OF INDIAN STANDARDS
मानक भवन, 9 बहादुरशाह ज़फर मार्ग, नई दिल्ली – 110002
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI-110002
www.bis.gov.in www.standardsbis.in

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Water Quality for Industrial Purpose Sectional Committee, CHD 13

FOREWORD

This Indian Standard was adopted by the Bureau of Indian Standards after the draft finalized by the Water Quality for Industrial Purpose Sectional Committee had been approved by the Chemical Division Council.This standard covers guidelines for selection of suitable chemical coagulant and disinfectant in a water treatment plant along with brief details of commonly used coagulants and disinfectants in raw water treatment.

Fresh water resources are formidably shrinking with increasing population and expansion of land used area, stressed the available resources of water to meet the need of society. The main natural sources of fresh water are Himalayan Glaciers and Seasonal rains to recharge the natural water bodies, which are contaminated during its course of flow with discharged effluents from local civic bodies and industrial sectors.

All naturally available water contains both dissolved and suspended impurities. The suspended impurities vary considerably with source, composition, charge, particle size, shape, and density. Coagulation and flocculation processes are used to separate the suspended solids from the water.

The choice of coagulant chemical depends upon the nature and magnitude of the suspended solid to be removed, the raw water conditions, the facility design, and cost of the amount of coagulant chemical necessary to produce the desired result.

For the purpose of deciding whether a particular requirement of this standard is complied with the final value, observed or calculated, expressing the result of a test or analysis shall be rounded off in accordance with IS 2 : 1960 'Rules for rounding off numerical values (*revised*)'. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

Indian Standard

SELECTION OF CHEMICAL COAGULANT AND DISINFECTANT IN A WATER TREATMENT PLANT — GUIDELINES

1 SCOPE

This standard covers guidelines for selection of suitable chemical coagulant and disinfectant in a water treatment plant along with brief details of commonly used coagulants and disinfectants in raw water treatment.

2 REFERENCES

The Indian Standards listed below contain provisions which through reference in this text, constitute provisions of this Indian Standard. At the time of publication, the editions indicated were valid. All standards are subject to revisions, and parties to agreements based on this Indian Standard are encouraged to investigate the possibility of applying the most recent editions of the Indian Standards:

IS No	*Title*
260 : 2001	Aluminium sulphate, non-ferric (*second revision*)
262 : 1982	Ferrous sulphate, heptahydrate (*second revision*)
299 : 2012	Alumino-ferric (*fifth revision*)
711 : 1970	Specification for ferric choride, technical (*first revision*)
1065 (Part 2) : 2019	Stable bleaching powder — Specification: Part 2 treatment of water intended for drinking
4200: 1984	Specification for sodium aluminate (*first revision*)
11673 (Part 2) : 2019	Sodium hypochlorite Solution: Part 2 Water treatment use (*second revision*)
15573 : 2018	Poly aluminium chloride (*first revision*)

3 TERMINOLOGY

3.1 Coagulation — A process/phenomenon to destabilize suspended colloidal particles/small particles by the addition of chemical reagent called coagulant, resultant to agglomeration and micro floc formation by destabilization of colloidal particles. Floc formation takes place where colloidal particles (0.1-1-micron size) collide with each other and create destabilized larger flocs in flocculation process. Coagulation basically involves three sequential steps:

a) Addition and mixing of coagulant in water;
b) Colloid /particle destabilization (charge neutralisation); and
c) Floc formation/agglomeration or flocculation (a physical process).

3.1.1 Coagulants on dissociation in water produce electrically +ve charged species (with high density charge), which neutralise the negative charges of suspended particles. Once the charge is neutralized, the colloidal and other suspended particles agglomerate. A high speed, rapid-mixing facilitates to disperse the coagulant and promotes particle collisions to achieve good coagulation. Proper contact time in the rapid-mix chamber is typically 1 to 3 min.

3.1.2 Objective of coagulation is not only to remove suspended particles in water but also to affect the removal of certain soluble materials by adsorption or precipitation for example, removal of natural organic matter (NOM) to reduce the formation of disinfection bye products, facilitating removal of pathogens and inorganic contaminants like arsenic compounds, phosphates, fluorides.

3.2 Coagulants — This is an inorganic or organic substance that initiates or facilitate a clarification process during water treatment. A coagulant together with other chemicals (as required), are added in water to aggregate dissolved contaminants, suspended particles (for example, colloidal and dispersed tiny particles) into large particles for their removal by sedimentation, clarification or any other solid removal process.

3.3 Flocculation — Following the first step of coagulation, a second process called flocculation occurs. Flocculation, a gentle mixing stage, increases the particle size from sub-microscopicmicro-floc to visible suspended particles. The micro-flocs are brought into contact with each other through the process of slow mixing. Collisions of the micro-floc particles cause them to bond to produce larger and visible bulky floccules which get settled. Sometimes another reagent called flocculants (along with coagulants) aids in the form of inorganic or organic polymers are added which promotes the formation of floc and strengthen the floc size and weight, to increase settling rate. Once the floc has reached its optimum size and strength, the water is ready for the sedimentation process. Required contact time for flocculation range from 20 min to an hour.

3.4 Sedimentation — A physical water treatment process under which suspended/insoluble/immiscible solids are settled due to gravity action. Removal of suspended particles by sedimentation depends upon the size and specific gravity of these particles (more than specific gravity of water).

4 COAGULANTS COMMONLY USED FOR TREATMENT OF RAW WATER

For raw water treatment, generally following chemicals are recommended in view of effectiveness of the coagulant. Chemical formulae and relevant Indian Standards are also mentioned along with forms available. Pre-polymerised salts are also available in high basicity/medium basicity grades offering more flexibility for selection of most suitable coagulant.

4.1 Aluminium Sulphate

It is also known as alumand available in two types namely, non-ferric and ferric having small quantity of ferric sulphate. It has been mostly used in water treatment since more than century as better alternatives were not available. Still it is one of widely used coagulant in water treatment.

Forms: Liquid and solid (slabs, lumps or coarse powder):

a) Non-ferric (IS 260 : 2001)
    1) Chemical Formula: $Al_2\ (SO_4)_3.14\text{-}18\ H_2O$
b) Alumino-ferric (IS 299 : 2012) — It contains mainly aluminium sulphate along with small quantity of ferric sulphate which also plays role of coagulant.
    1) Chemical Formula: $nAl_2(SO_4)_3.(1\text{-}n)\ Fe_2(SO_4)_3.14\text{-}18\ H_2O$, where ‘n’ is variable.

4.2 Sodium Aluminate

Sodium aluminate is used in conjunction with alum for treatment of water (having low *p*H) where high *p*H is desired for effective coagulation. It is very useful adjunct to the lime soda softening process, particularly when magnesium is also present in water as it coagulates colloidal magnesium hydroxide.

a) Chemical formula: $Na_2Al_2O_4.\ XH_2O$
b) Forms: Solid and liquid (*see* IS 4200)

4.3 Polyaluminium Chloride (PAC)

Polyaluminium chloride (PAC) is general name given to polyaluminium chloride compounds, namely polyaluminium chloride hydroxide and polyaluminium chloride hydroxide sulphate. When it is to be used for treatment of water for supply of potable water, it is recommended that PAC is produced from virgin raw materials to avoid any contamination of toxic and hazardous substances.

a) Chemical formula: [Al (OH)a Clb]n where a and b are variables; $a + b = 3$; $n \approx 15$ and $a \geq 1.05$

    $[Al\ (OH)_a\ Cl_b\ (SO_4)_c]n$ where a, b, c are variables and $(a + b + 2c) = 3$ and $a \geq 1.05$, and n~15
b) Forms: Solid and liquid
c) Grades: High basicity and Medium basicity

High basicity grades are preferred for waters having low alkalinity (< 50 ppm) and where low *p*H fall is desired or when higher doses are needed (*see* IS 15573).

4.4 Aluminium Chlorohydrate

Aluminium chlorohydrate (ACH) is a specific aluminium salt which is used in cosmetics as an antiperspirant and as a coagulant in water purification. It is commercially available in solid and liquid forms.

In water purification, this compound is preferred in some cases because of formation of high density electrically charged species (Ionic species), which makes it more effective for destabilizing and removing suspended materials than other aluminium salts, such as aluminium sulphate, aluminium chloride and various forms of polyaluminium chloride and polyaluminium chlorosulphate, in which the aluminium structure results in a lower net charge than aluminium chlorohydrate. Further, the high degree of neutralization of the HCl results in minimal impact on treated water *p*H when compared to other aluminium and iron salts. It is effective at cold temperature and particularly suited for low alkalinity raw water.

a) Chemical formula: $Al_2(OH)_5Cl$
b) Forms: Solid and liquid

4.5 Ferric Chloride

It is commercially available in the form of anhydrous powder, hydrated material and liquid at various concentrations. Solid anhydrous forms fume on exposure to air giving vapours of HCl. Both forms are highly corrosive and require special attention during its storage and handling. Due to colour and residual iron ions, it is rarely used in treatment of raw water for potable use. When treated water has to undergo further process like reverse osmosis (RO), it is extensively used. It also has predominant use as coagulant for sewage and industrial waste water treatment.

a) Chemical formula:Anhydrous: $FeCl_3$
b) Hydrates: $FeCl_3.6H_2O$
c) Forms: Solid (anhydrous powder or deliquescent crystals of hydrated form) and liquid (*see* IS 711).

4.6 Ferrous Sulphate

It is produced as hydrated form having green or bluish green crystals. It is rarely used for treatment of raw water because soluble ferrous ions need to be oxidised to ferric ion for its removal as floc or precipitate/sludge from treated water. Generally, its major use is for treatment of waste water.

a) Chemical formula: $FeSO_4.7H_2O$

b) Form: Solid (*see* IS 262)

4.7 Ferric Sulphate

Ferric sulphate is used as a primary coagulant in water treatment particularly when a broad coagulation *p*H range is desired, as it is effective between 4-11 *p*H.

a) Chemical formula: $Fe_2(SO_4)_3$

b) Form : Crystalline and liquid having 39-45 percent ferric sulphate

4.8 Poly-electrolytes

Poly-electrolytes are long-chain polymers having high molecular weight and are widely used in industry as coagulant aids together with the regular inorganic coagulants. Anionic (negatively charged) poly-electrolytes are often used along with metal coagulants. Low-to-medium weight positively charged (cationic) poly-electrolytes can also be used alone or in combination with the aluminum and iron type coagulants to attract the suspended solids and neutralize their surface charge. Poly-electrolytes are effective over a wider *p*H range than inorganic coagulants. They can be applied at lower doses, and they do not consume alkalinity. They produce smaller volumes of more concentrated, rapidly settling floc. The floc formed from use of a properly selected polymer will be more resistant to shear, resulting in less carryover and a cleaner effluent.

As per WHO, presence of unreacted monomers in polyelectrolytes is a matter of concern to public health. As a result some countries have banned its use in drinking-water treatment. Though some claims have been made that the poly-electrolyte of starch base can be used for drinking water treatment however potability of such treated water needs to be established first. Thus, due to potential carcinogenic nature of polyelectrolytes, treatment of raw water using polyelectrolyte is restrictively recommended for use of such treated water for industrial sector/application and strictly not to be used for treatment of water intended for drinking.

5 GUIDELINES OR GUIDING FACTORS FOR SELECTION OF COAGULANT

Final selection of the coagulant (or coagulants) and dosing rate should be based on thorough Jar testing and plant scale evaluation. Factors for choice and selection of coagulant should be based upon raw water quality, effect upon downstream treatment process performance, desired quality of treated water in terms of turbidity, NOM, *p*H, TDS etc. and cost of inventory (coagulants/chemical), method and cost of operations and sludge handling and disposal and finally net overall cost at the dose required for effective treatment to achieve desired goals of treatment.

5.1 Source of Raw Water

River, canal, pond, lake, dam, etc.

5.2 Raw Water Quality

Turbidity, alkalinity, *p*H, hardness, temperature, colour, odour and taste (*see* Note below)

NOTE — For taste evaluation, adequate precaution should be taken after assessing raw water quality for clarity and odour. It is recommended that taste evaluation should be avoided if raw water is suspected of effluent contamination.

5.3 Type of Process Equipment

5.3.1 *Existing Plants* — Type of clarifier and related systems of storage, chemical dissolution, piping and dosing etc.

5.3.2 *Upcoming Plants* — For design of upcoming plants, factors for consideration include:

a) Land available/required,

b) Capital cost, and

c) Operating and maintenance cost.

5.3.3 *Simplicity or Ease in Plant Operation* — Safety, environment, sludge handling and disposal etc.

5.3.4 *Desired Quality of Treated Water* — In terms of TDS, *p*H, sulphate content etc.

5.3.4.1 *In terms of uses* — Potable or industrial application and or demineralisation.

5.3.4.2 *In terms of physio-chemical parameters of treated water* — Colour, taste, odour, TDS, *p*H, hardness, conductivity, disinfection by products (DBP), level of sulphates, chlorides and residual aluminium or iron content. For household usage treated water quality need to comply IS 10500, while for other usage it need to satisfy other national or individual industry standards.

5.3.4.3 *Source of raw water* — It is important to know the source of raw water (water lifted from underground source or natural water bodies) to ascertain its continuous availability as well as its variation in quality due to season, pollution or other external factors which will affect critical parameters of plant operation.

6 RAW WATER QUALITY

6.1 Turbidity

Turbidity in water is due to suspension/dispersion of fine particles (like clay, silt etc.), colloids of minerals and organic impurities which normally have negative charge on it. Generally in low turbidity water (< 10 NTU), inorganic coagulant which quickly generates floc and forms stable sludge bed is preferred. Under moderate turbidity (10-100 NTU), use of any PAC or alum or iron salt will be successful, and selection in this category is done based on other desired factors like economy, safety, treated water quality etc. In case of high turbidity (> 100 NTU) or where there is rapid change in turbidity, PAC or PAC with little alum is most suitable over required large additions of alum or ferric sulphate to get better operational efficiency and superior water quality (low TDS, low *p*H depression etc.).

6.2 Alkalinity

While selecting a metal salt coagulant, such as alum, ferric salt or PAC, alkalinity is of critical importance as these coagulants require some alkalinity for their effective performance. At low alkalinity (< 50 ppm), high basicity coagulants, such as PAC or aluminium chlorohydrate (ACH) are reported effective. For alumor ferric salts, alkalinity need to be increased by addition of alkali, such as NaOH, Na_2CO_3 or $Ca(OH)_2$ or by use of sodium aluminate. At higher alkalinity > 50 ppm, normally all coagulants will function well.

6.3 *p*H

*p*H of raw water has important role to determine/exclude certain coagulant because each coagulant has its own optimum *p*H zone to perform effectively. Ferric salts perform well in acidic conditions, while in case of ferrous sulphate, the *p*H > 9.5 is maintained to ensure complete precipitation of iron. Reported optimum *p*H range for alum is 5.5 - 6.5 and for PAC it is 5.0 – 8.0. Effect of *p*H fall in treated water is also important to note as in case of alum and ferric salts, *p*H fall is substantial.

6.4 Temperature

All commonly used coagulants perform well when water temperature is 10^0C to ambient. At temperatures lower than 10^0C, efficiency of alum and iron salts declines largely. Thus in winter, whenever water temperature is likely to fall below $10\ ^0$C, PAC is the most suitable as it functions well at a broad temperature range.

6.5 Hardness

There will be always some hardness in raw water due to calcium and magnesium salts. Whenever it is required to reduce temporary hardness of water, generally lime is added for softening water. Although lime sludge is dense, to capture lime fines, coagulant is required. Lime sludge also need to be dewatered for its separate disposal. Major criterion for efficient lime softening is *p*H control, *p*H should be (9.8 -10.2), a coagulant leading to high depression of *p*H will effect softening efficiency, thus not suitable. Thus high basicity salts like PAC/ACH are found to be more suitable for water requiring lime softening process.

6.6 Dissolved Organic Carbon (DOC)/Colour

Maximum removal of dissolved organic carbon or total organic carbon (TOC) or natural organic matter (NOM) or colour is critical in selection of a proper coagulant, while providing water which is neither corrosive nor scaling. The coagulants which can remove DOC by complexation with it (usually at *p*H 5.5 – 7.0), while preserving alkalinity for turbidity precipitation are most suitable. Suitable selection is normally achieved by testing each chemical in the laboratory followed by plant trial. In waters with both NOM and suspended particles, required dose of coagulant is typically determined by the NOM concentration.

6.7 Taste and Odour

Coagulants have a little role in removal of odour and improvement in taste of treated water, which is generally achieved by treating water by passing through activated carbon beds.

6.7.1 *Process Equipment (Plant Design)* — Unlike raw water quality, type of plant has little impact on choice of coagulant, in almost all of the existing plants, change of coagulant is possible with or without some minor changes. However, if a new plant is to be designed, then operating and capital cost of the plant as well as required space can be reduced by selection of suitable form (liquid or solid) and type of coagulant.

In case of liquid coagulants, equipment handling for example, agitators, solution tanks for dissolution of solid coagulants are not required, further covered space for storage of solid coagulants is not needed. In case of liquid form of coagulants, size of required piping and dosing pumps depends on volume of dose and is significantly low for polymeric coagulants, which are normally dosed without dilution.

Lime or alkali addition is required in many cases to increase *p*H of treated water due to fall in *p*H caused by a coagulant (ferric chloride, ferrous sulphate, alum) while for other coagulants (ACH, PAC, sodium aluminate), *p*H drop is minimal and thus additional treatment to boost *p*H may not be required. This reduces cost of lime storage area, lime dissolution tanks, related piping and dosing arrangements. In same fashion at high turbidity, in case of some coagulants, flocculants like Pes (for industrial treatment) are not required thus selection of appropriate coagulant can save capital and operating cost on lime and PE storage, dissolution and dosing. Some coagulants generate very low sludge which will attribute in reduction of size of required sludge handling and disposal unit. Use of such chemicals will lead to significant reduction in capital cost and required space and this is also normally associated with low operating costs and good housekeeping.

6.8 Safety, Environment and Ease in operation

6.8.1 *Safety*

It is essential to find hazardous nature of the coagulant as well as special precautions for its handling and usage. Further it is also important to know volume or quantity of coagulant required for a period (say yearly).

If a coagulant is available in the liquid form, then merits of using it in liquid form must be assessed. Liquid coagulants are relatively safe and easy to store and handle as compared to its solid forms which require many extra operations including manpower or equipments (hoist/cranes/forklifts) to unload, stock, transfer, dissolve, removal of insoluble from dissolution tanks etc. Use of coagulants in liquid form enhances safety as operations are in closed system. Further some coagulants work efficiently at low dose and without any dilution; thus low quantity to handle such coagulants provide more safety.

6.8.2 *Environment*

As per recent research studies, presence of sulphate in sewage and its conversion to hydrogen sulphide (H_2S) and further to sulphuric acid by bacteria can be reduced to a great extent for reducing pollution and saving substantial cost of sewer corrosion or its control. It is reported that sulphate free coagulants can thus drastically reduce generation of H_2S in sewer and switch over to sulphate free coagulants can decrease pollution due to H_2S and sewer corrosion significantly. Thus latest trend is to use sulphate free coagulants.

Pre-polymerised salts of iron and aluminium are very efficient, require small quantity of iron or aluminium ions for coagulation thus requiring less exploitation of natural resources of minerals of these metals. Further sludge generation is reduced to a great extent.

6.8.3 *Ease in Operation*

One should preferably select a coagulant which has wider applicability that is, which is effective during wide variation in quality of raw water, *p*H, temperature, turbidity etc. rather than frequent changeover of one coagulant to other due to poor performance of a coagulant in use.

A few coagulants are used as such or low dosing volume is required for same performance as compared to other coagulants making plant operation compact and easier and thus requiring less manpower and supervision. These merits are assessed in terms of economics, safety, capital cost to conclude the choice of coagulant.

6.9 Desired Water Quality

6.9.1 *Effect of Coagulation on Quality of Treated Water*

Since coagulants are directly added to raw water during treatment, its nature, purity, quantity used and reactivity etc. have direct impact on the quality of treated water. In the municipal water segment, plant is often run to supply the best quality of water as per government regulations while cost being secondary priority. In an industrial plant, water is treated as per requirement of its process keeping economics as one of the major consideration. By considering desired crucial parameters of quality a few options will be eliminated thus making process of selection relatively easier.

High dose of conventional salts of aluminium or iron consume natural alkalinity of water significantly, leading to fall in *p*H of treated water (may require *p*H boosters) while increasing TDS/ionic load and conductivity significantly. High dose required for some coagulants may lead to high TDS which can affect taste of water or food items prepared from such water. Iron based coagulants, many times leave residual colour, or cause yellowing of water on storage due to oxidation of residual ferrous salts. Thus these are not recommended for use in water treatment for house hold usage if other alternates are available.

In case of pre-hydrolysed salts of aluminium and iron depression in *p*H is very low and increase in ionic load/TDS due to coagulant is about 70-80 percent lower leading to better quality of water having low conductivity. Residual aluminium in pre-hydrolysed aluminium coagulants PAC/ACH is also low as compared to alum usage (*see* Table 2) .

Effect of selected coagulant on disinfection bye products (DBP) also need to be looked into to ascertain that treated water is within permissible limits with respect to DBP. Newly developed pre-hydrolysed coagulants like polyferric chloride/sulphate (PFC or PFS) or ACH or PAC contribute lower (12-25 percent) ionic load (TDS) as compared to conventional salts of aluminium or iron. Thus use of these relatively new coagulants is extremely beneficial in demineralisation (DM) process as it leads to reduction in regeneration of resin beds, thus saving cost of regeneration chemicals (caustic and acid), resins, power, labour and maintenance.

7 FUNDAMENTALS OF DISINFECTION OF WATER

As raw water is invariably contaminated with various pathogens (bacteria, viruses and amoebic cysts) causing killer diseases like typhoid, dysentery, cholera, diarrhoea, giardiasis, gastroenteritis etc, process of effective destruction or inactivation of the pathogens called as “disinfection” is a necessary step in water treatment for providing safe potable water. Other physio-chemical steps of water treatment like coagulation, flocculation, sedimentation, filtration, aeration etc. assist in destruction or removal of pathogens to some degree but to obtain safe water, disinfection is still required. Disinfection is generally carried by following process.

a) Boiling;

b) Membrane filtration;

c) Radiation UV, X- rays, gamma rays; and

d) Treatment by chemicals, such as chlorine, chlorine producing compounds like bleaching powder, sodium hypochlorite, chlorine dioxide, bromine, iodine and ozone etc.

7.1 Mechanism

7.1.1 Disinfection/destruction or inactivation of pathogens can be explained by following four mechanisms:

a) Damaging cell wall;

b) Changing cell permeability;

c) Changing colloidal nature of the cell protoplasm; and

d) Inactivation of enzyme systems responsible for metabolic activities.

Table 1 Comparative Table for Illustrating Commonly Used Coagulants like Alum and PAC for Treatment of Potable Water

(*Clause* 6.9.1)

Sl No.	Parameter	Alum	PAC
(1)	(2)	(3)	(4)
i)	**Raw water quality**		
	a) Turbidity		
	Low and medium turbidity	Good	Good
	high turbidity	Poor	Good
	b) Alkalinity		
	<50 ppm	Poor	Good
	> 50 ppm	Good	Good
	c) *p*H of raw water	5.5-6.5	5.0 – 8.0
	d) Temperature of raw water		
	< 10 °C	Poor	Good
	10°C -ambient	Good	Good
ii)	**Type of plant**		
	a) Existing plants based on alum usage	Suitable	PAC can be used in alum-based plants with or without minor modifications.# Alum solution/ liquid alum tanks can also be used for storage of PAC
	b) Flock/sludge settling time	High	Low
	c) Output of treated water	As per designed capacity	Normally higher than designed capacity due to low sludge and easy filtration
	d) Existing plants designed on PAC usage	Alum can be used in PAC based plants with minor modifications	Suitable
iii)	**New plants under design**		
	a) Form of coagulant	Preferred liquid form if available, as agitator and solution tanks not needed. Solid form can also be used as storage and transportation likely to be easier.	Liquid form preferred, if available. Solid form can also be used, as storage and transportation will be easier.
	b) Required land and covered space	High	Low particularly in case of liquid form.
	c) Hygiene and cleanliness of plant	Low in case of solid alum #	High
iv)	**Safety**		
	Solid form of coagulant	Average	Average
	Liquid form of coagulant	Good	Good
v)	**Environment-friendly**	Medium	Good
vi)	**Ease in operation**	Medium	Good
vii)	**Quality of treated water**	Fair*	Good

# In view of large quantity and nature of supply (loose) as per prevailing practices in India.

* Alum appears to be superior compared to PAC only for removal of DOC particularly coagulation at low *p*H (enhanced coagulation). However, this depends on particular raw water and in most cases it will not be an issue.

7.1.2 Chemical disinfection involves minimum two steps namely:

a) Penetration of the disinfectant through the cell wall; and
b) Reaction with enzymes within the cell.

7.1.3 Residual disinfection is also necessary to provide a partial safeguard against low-level contamination and growth within the distribution and storage system. Different disinfection practices may be required to treat the different type of pathogens effectively.

7.2 Disinfection Practices Commonly used in Water Treatment

Generally two type of chemical disinfectants are used, namely:

a) Oxidizing chemicals, which includes halogens and halogen releasing compounds, chlorine dioxide and other oxidants, such as ozone, potassium permanganate etc; and
b) Metal ions, such as silver. Rarely other type of chemical disinfectants, such as acids and bases are used for disinfection. Other techniques include use of radiations for example, ultraviolet, gamma, X- rays and microwaves for destruction of microorganisms, out of which UV radiation is in use commercially. Occasionally membrane filtration is also used.

A comparative chart for different disinfectants are also provide din the Table 2.

7.3 Commonly used Disinfectants

Commonly used disinfectants are mentioned in **7.3.1** to **7.3.6.**

7.3.1 *Chlorine*

Chlorine is commercially available in small cylinders as well as in large cylinders (tonners) having 900 kg of chlorine, where it is in the form of amber coloured oily liquid due to high pressure in the cylinder. Liquid chlorine is vapourised to get chlorine in gaseous form for treatment of water.

Chlorine reacts with water to form hypochlorous acid (HOCl) (*see* equation1) which further dissolves into hypochlorite ions (OCl^-) and H^+ (*see* equation 2).

$$Cl_2 + H_2O \rightleftharpoons HOCl + H^+ + Cl^- \qquad \text{equ. (1)}$$

$$HOCl \rightleftharpoons H^+ + OCl^- \qquad \text{equ. (2)}$$

Both above said reactions (1) and (2) are reversible. The undissociated HOCl is about 100 times powerful disinfectant than the hypochlorite (OCl^-) ion. Free available chlorine in water is defined as the chlorine existing in water as HOCl and OCl^- ions.

Both reactions (1) and (2) are dependent on *p*H of water. Above *p*H value of 3, which is normally case

Table 2 Comparative Chart for Different Disinfectants

(*Clause* 7.2)

Sl No. (1)	Disinfectant (2)	Effectiveness to Destroy Common Pathogens (3)	Disinfection by Products (DBPs) (4)	Residual Effects (5)	Ease of Application (6)	Ease to Detect efficiency of Disinfection (7)	Cost (8)	Safety Aspect (9)	Effective *p*H Range (10)
i)	Chlorine	Yes	THM and HAA	Fair	Poor	Easy	Lowest	Low	5.5-8
ii)	Bromine	YES	Br-THM and Bromoamines	Fair	Poor	Easy	High	Low	5.5-8.5
iii)	Iodine	YES	I-THM and Hypo- Iodous acid	Fair	Medium	Easy	Expensive than Chlorine	Good	5.5-8
iv)	Bleaching Powder	Yes	THM and HAA	Fair	Easy	Easy	High	Fair	5.5-8
v)	Sodium Hypochlorite	Yes	THM and HAA	Fair	Easy	Easy	High	Fair	5.5-8
vi)	Chlorine dioxide	Yes	None	Good	Medium	Easy	Very High	Good	Wide *p*H range
vii)	Ozone	Yes, (A superior bactericide)	Not Established	NIL	Difficult	Rapid Field test not available	10-15 times than Chlorine	Good	Wide *p*H range
viii)	UV Radiation	YES	NONE	NIL	Easy	--do---	High	Good	Wide *p*H range

for raw water, chlorine completely exists in form of hypochlorus acid (HOCl). Further as *p*H increases from 5.5, dissociation of HOCl to hypochlorite ion (OCl) increases. Approximate percent of HOCl at different *p*H value of water is given below in the tabular form.

*p*H of water	5.5	6.0	7.5	8.0	9.5
Percent of HOCl	100	96	50	10	0

The addition of chlorine does not produce any marked change in *p*H of the natural waters. Although chlorine is employed primarily for microbial disinfection, it also acts as an strong oxidant and is consumed by many organic and inorganic materials present in the water thus can remove or assist in removal of many undesirable impurities in the water. Sufficient time and dose of chlorine is must for chemical reactions and disinfection and to leave some unreacted chlorine as residual for disinfection of water during storage and transportation. Chlorine is dosed either in the gaseous form or in the form of a solution made by dissolving gaseous chlorine in a small auxiliary flow of water by getting chlorine gas from chlorine cylinders. It is extensively used in medium to large water treatment plants, however it requires elaborate safety practices and use of chlorine evaporators and auxiliary equipments.

Chlorine reacts with organic matter in water to produce trihalomethane (THM), halogen acetic acid (HAA) mainly dichloro and trichloro acetic acids and other halogen disinfection byproducts (DBPs), which if present in large quantity may sometimes be a matter of health concern. Formation of these DBPs can be controlled by optimisation of treatment systems (*see* IS 646).

7.3.2 *Bleaching Powder/Calcium Hypochlorite*

Bleaching powder is another source of chlorine. Its grade having 30-35 percent available chlorine is extensively used, and is commonly called as "stable bleaching powder". Its use is simple, relatively safe and does not require power during its application, but has demerit of poor stability, difficulty in storage due to its hygroscopic nature and expensive to use. It is generally used in small installations (*see* IS 1065).

High strength bleaching powder having 65-70 percent available chlorine is also used due to its high stability and non-hygroscopic nature but it is more costlier and require safety in handling.

7.3.3 *Sodium Hypochlorite Solution*

Chlorination of water is also done by sodium hypochlorite having 10-15 percent of available chlorine at ambient temperatures. Its stability is greatly affected by heat, light, *p*H and presence of heavy metal ions. Storage temperatures should not exceed 32°C, above which decomposition rate is too high. Due to stability issue, commercial sodium hypochlorite is rarely used that too only in small plants (*see* IS 11673).

As compared to chlorine use of sodium hypochlorite is quite expensive.

7.3.4 *Chlorine Dioxide (ClO_2)*

Due to concerns about production of trihalogen methane (THM) during disinfection by chlorine and also safety hazards in storage, transportation and handling of bulk chlorine, use of chlorine dioxide is becoming more popular in recent years. Chlorine dioxide has very short shelf life and hence, is generated immediately prior to application. Chlorine dioxide decomposes in water to form chlorite and chlorate. Chlorine dioxide is unstable and subject to explosion in gaseous form but aqueous solutions of the gas are stable and safe. Its efficiency as germicide is least affected between *p*H 6 - 10 and it does not combine with ammonia and many other organic impurities before oxidising them, thus DBPs are low and not a matter of concern. Dosage of chlorine dioxide remains less than chlorine due to its higher oxidising capacity.

7.3.5 *Ozone (O_3)*

It is produced by passing dry air or oxygen through a high voltage electric field. Ozone being unstable it breaks down to normal oxygen (O_2) and nascent oxygen (O), latter being a powerful oxidant and disinfectant. Its dose is typically in the range of 2-5 mg/l. It is a superior pathogen killer than chlorine and its compounds and is highly effective in removal of tastes, odours, colour, iron and manganese, but it must be dosed sufficiently to complete oxidation before initiation of disinfection. Its efficiency of disinfection is unaffected by *p*H or temperature over a wide range. Ozone forms DBPs, whose adverse effects are not yet established.

Demerits of ozone treatment include:

a) High cost of production (10-15 times than chlorine);
b) Its generation on site due to unstability; and
c) Inability to provide residual protection.

Despite these demerits, ozone is extensively used in many developed countries particularly in municipal water segment of Europe and Canada.

7.3.6 *Other Halogens*

7.3.6.1 *Bromine*

It is commercially available as heavy dark reddish-brown liquid, which upon addition to water forms hypobromous acid (HOBr) and its dissociation leads to formation of hypobromite ion $(OBr)^-$. Bromine reacts with ammonia and organic matter in water. It has been used on a limited scale for disinfection on small installations like swimming pools. Due to its high cost and low effectiveness, it is not used for water treatment in municipal/ Industrial segment.

7.3.6.2 *Iodine*

Addition of solid iodine in water results in formation of hypoiodous acid (HOI) and hypoiodite ion $(IO)^-$. Iodine has same disinfecting power as chlorine and is less dependent on *p*H, temperature, time of contact and can also kill aerobic cysts, and provides long lasting protection. Iodine oxidises ammonia and phenols present in water, thus produces lower DBPs than chlorine. Being more costly than chlorine, iodine has been used in swimming pools and in very small installations.

7.3.6.3 *UV radiation*

Ultraviolet radiation may kill a cell, retard its growth and change its heredity. Depending on the dose of radiation, one or all above said processes may happen. Effective region of wavelength is 250 – 265 nm for disinfection. For this purpose UV light produced by mercury lamp is used for good disinfection. Sufficient intensity and time of exposure is applied to clear water flowing in thin films. Presence of iron even at low concentration of 1 ppm can drastically absorb >80 percent of UV radiation and water depths of about 12 cm are desired for good disinfection.

Merits of UV radiation are that, no foreign matter is actually introduced and no taste or odour is produced. Demerits of UV treatment include:

a) Lack of residual effect;
b) expensive equipment; and
c) lack for a rapid field test to check treatment efficiency.

Use for UV radiation in industrial/potable water treatment has typically been restricted to small facilities.

7.4 Guidelines or Guiding Factors for Selection of an Efficient Disinfectant

Efficiency of disinfection will obviously depend on the nature of the disinfectant. The end products of reactions which occur when disinfectant is added into water determine efficiency of disinfection. The course of these reactions are influenced by the character of water and its constituents. Adequate concentration of a chemical disinfectant must be added to maximize destruction of organisms.

Undermentioned five main factors must be considered during selection of suitable disinfectant.

7.4.1 *Physio-Chemical Parameters of the Water to be Treated*

Higher the temperature, faster is the disinfection as rates of chemical reaction increase with increase in temperature thus temperature of water must be suitable for reactions between selected disinfectant and water. The range of *p*H of water to be treated is crucial to evaluate a disinfectant since bactericidal efficiency varies with *p*H. Type of organic matter and pollutants in water also play important role for selection of disinfectant as these will also consume the disinfectant.

Type and quantity of suspended particles will also affect disinfection as some microorganism may be sheltered from disinfectant when deeply embedded in the suspended particles, thus better clarity of treated water is required.

7.4.2 *Type, Condition and Density of Pathogens*

Each type of organism has different cell structures and enzyme systems from other organisms, therefore action of disinfectant varies on different pathogens. Viruses in general are more resistant than bacteria and thus need high concentration and longer contact time of disinfectant. Cysts are very resistant. Conditions in which the organism occur are also likely to affect the efficiency for example, cell inside the clump may get protection from disinfectant when cells are clumps together. High density of the pathogens also affects the efficiency of the disinfectant.

7.4.3 *Contact Time Available for Disinfection*

The destruction of organisms increase with contact time available for disinfection, it is limited by the design of the plant and is usually >30 minutes. If the minimum contact time is not available then dose of the disinfectant needs to be enhanced.

7.4.3.1 *Criterion for a good disinfectant*

For a disinfectant to be effective in water treatment plant, it must possess the following properties:

a) For a particular water for treatment it should be capable to destroy present pathogens sufficiently within available contact time;
b) It should be possible to detect efficiency of disinfection easily by a practical, rapid and simple method; and
c) It should leave residual effect to avoid undesirable bacterial growth during storage and distribution up to end-user.

7.4.4 *Quantity of Water to be Treated*

For large facilities, gas chlorination or chlorine dioxide are recommended.

7.4.5 *Safety/Hazard Aspects*

7.4.5.1 Disinfection by products (DBP) formed by use of the disinfectant should not render water toxic or unacceptable due to odour, colour and taste.

7.4.5.2 Safety in storage, transportation and handling of bulk materials should also be considered while selecting a proper disinfectant.

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ANNEX A

(*Foreword*)

EXPERTS WHO MADE SIGNIFICANT CONTRIBUTION TO THE DEVELOPMENT OF THIS STANDARD

Organization	*Representative(s)*
Bhabha Atomic Research Centre (BARC), Mumbai	Shri K. P. Bhattacharyya, (***Chairman***) CHD 13 Shri Shivayyanamath. S. (*Alternate*)
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Consumer education and Research Centre, Ahmedabad	Ms Anindita Mehta Ms Dolly Jain (*Alternate*)
Department of Industrial Policy & Promotion, New Delhi	Shri T.S.G. Narayanan Shri Nand Lal (*Alternate*)
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Maharashtra State Electricity Board, Chandrapur	Shri V. P. Ghodmare Shri Rajesh (*Alternate* I) Dattatraya Chivane (*Alternate* II)
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National Environment Engineering Research Institute, Nagpur	Dr Pawan Labhasetwar Er S. P. Andey (*Alternate*)
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The Fertilizer Association of India, New Delhi	SHRI MANISH GOSWAMI SHRI N. R. KAMAT (*Alternate*)
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